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(54) An apparatus for extracting skin pattern features and a skin pattern image processor

Gerät zur Merkmalextraktion von Hautmustern und Bildprozessor für Hautmuster

Appareil pour extraire des caractéristiques de formes de peau et processeur d'images de formes de peau

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- **IEE PROC.-VIS. IMAGE SIGNAL PROCESS., vol. 141, no. 2, April 1994, pages 87-94, XP000610431 B. G. SHERLOCK, D M. MONRO ET K. MILLARD: "Fingerprint enhancement by directional Fourier filtering"**
- **IEEE INT. SYMP. ON COMPUTER VISION, 21 November 1995, CORAL GABLES, CA, USA, pages 109-114, XP000609299 T. KAMEI ET M. MIZOGUSHI: "Image filter design for fingerprint enhancement"**

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Description

[0001] This invention relates to an apparatus for extracting features of skin pattern images and an image processor for smoothing and enhancing features of the skin pattern images making use of the extracted features. More particularly, the invention relates to an apparatus for extracting such features as ridge line directions, ridge line pitches or their combination of skin pattern images for fingerprint verification, fingerprint classification or palm print verification, and an image processor for processing skin pattern images for enhancing ridge lines by eliminating noises of the images making use of the extracted features.

[0002] As a prior art, there is a Japanese patent application entitled "An Apparatus for Striped Pattern Extraction" and laid open as a Provisional Publication No. 77138/'76. In the prior art, which is hereafter called a first prior art, an apparatus is disclosed for eliminating noises from such striped images as fingerprints or tree rings and extracting both stripe patterns and directional patterns of the striped images.

[0003] FIG. 14 shows principle of the apparatus. An image in a subregion 100 with its center at a small square 101 is represented by a set of pixel data. Each small square in the subregion 100 represents a pixel, and a numeral 1 or a blank in a small square means corresponding pixel value 1 (black) or 0 (white). Filter data sets 102, 103, 104, 105, and 106 for masking are prepared corresponding to no direction *d*0 and four directions *d*1, *d*2, *d*3, and *d*4 respectively. By calculating their sum of products with the pixel data of the image exampled in FIG. 14, values +5, 0, +11, +3 and -7 are obtained corresponding to each direction *d*0 to *d*4 respectively.

[0004] From these values, ridge direction at pixel 101 of the image is determined to the direction *d*2 which gives the maximum value +11 and stripe pattern value at the pixel 101 is determined to the maximum value +11.

[0005] Thus, stripe patterns and directional patterns are extracted as features of striped images in the first prior art.

[0006] Smoothing of extracted features is sometimes necessary for decreasing noise influence on the features. For the purpose, a smoothing method is disclosed in a Japanese patent application entitled "Method of Smoothing a Ridge Direction Pattern and an Equipment used therefor" and laid open as a Provisional Publication No. 18195/93. This smoothing method, hereafter called a second prior art, is based on a minimum energy principle.

[0007] From ridge direction data extracted with their reliability coefficients, a smoothed ridge direction pattern is determined in the prior art, wherein it is assumed that direction data extracted with the higher reliability need the more energy to be smoothed into a direction pattern and that it needs the more energy to smooth direction data into a direction pattern the more different from neighboring direction patterns. Therefore, a direction pattern which gives a minimum value of an evaluation function, linear summation of those energies, is determined as the smoothed direction pattern of a subregion.

[0008] However, pixel values of a striped image vary periodicaly in a direction perpendicular to the stripes. Therefore, when stripe phase of a striped image is nearly orthogonal to the stripe phase of the filter data for masking used in the first prior art, the sum of products results nearly 0 even when both directions coincide with each other. This means that the extracted direction patterns and, consequently, the extracted stripe patterns become unreliable influenced by noise data, making precise ridge line pitch extracion difficult.

[0009] In the second prior art, smoothing of ridge direction patterns is performed based on extracted ridge directions. So, when extracted ridge direction data are not reliable, precise smoothing of ridge direction patterns and, consequently, precise smoothing of ridge line pitches can not be performed.

[0010] Another prior art document can be found in IEE PROC.-VIS. IMAGE SIGNAL PROCESS., vol. 141, no. 2. April 1994, pages 87-94, XP000610431 B. G. SHERLOCK, D M. MONRO ET K. MILLARD: "Fingerprint enhancement by directional Fourier filtering". In this document, a new method of enhancing fingerprint images is described, based upon rionstationary directional Fourier domain filleting. Fingerprints are first smoothed using a directional filter whose orientation is everywhere matched to the local ridge orientation. Thresholding then yields the enhanced image.

[0011] It is the object of the present invention to overcome the drawbacks of the prior art documents.

[0012] The object is solved by the apparatus according to independent claims 1 and 2.

[0013] Further advantageous features of the present invention will become apparent by the dependent claims, the description and the accompanying drawings.

[0014] The invention provides an apparatus for extracting features such as ridge directions, ridge line pitches or their combination from skin pattern images with high reliability regardless of the stripe phase difference, and a skin pattern image processor for precisely enhancing ridge line patterns by eliminating noises from the skin pattern images.

[0015] Furthermore, a plurality of filters consisting of two-dimensional weight coefficient matrix are prepared in the present invention according to kinds of features to be extracted.

[0016] A skin pattern image is filtered with each by each of the plurality of filters by convolution calculation on a real plane or by product calculation of each frequency component on a Fourier transformed plane.

[0017] Contrast or image intensity, that is, a square sum of pixel values of a subregion of each filtered image thus calculated is compared with each other and a feature parameter represented by a filter which gives a largest image intensity is determined as the feature to be extracted of the subregion of the skin pattern image.

[0018] And from pixel values of the image data of subregions filtered by a filter giving the feature of the subregion, image data of the subregion with enhanced feature can be obtained at the same time.

[0019] The foregoing, further aspects, features, and advantages of this invention will become apparent from a consideration of the following description, the appended claims, and the accompanying drawings in which the same numerals indicate the same or the corresponding parts.

[0020] FIG. 1 is a block diagram illustrating a first embodiment of the invention.

[0021] FIG. 2 illustrates an example of a filter designed on a Fourier transformed plane.

[0022] FIG. 3 shows frequency bands of five filters prepared for extracting ridge line pitches.

[0023] FIG. 4 shows shading images of the five filters of FIG. 3.

[0024] FIG. 5 illustrates an example of arrangement of subregions in a skin pattern image.

[0025] FIG. 6 is a block diagram of a filtering means 24 of a second embodiment of the invention.

[0026] FIG. 7 is a block diagram of a feature extracting means 30 of a third embodiment of the invention.

[0027] FIG. 8 illustrates a subregion *C(m, n)* and neighboring subregions *C(m', n')* around the subregion *C(m, n)*.

[0028] FIG. 9 is a flowchart illustrating operation of the feature extracting means 30 of FIG. 7.

[0029] FIG. 10 is a block diagram illustrating a fourth embodiment of the invention.

[0030] FIG. 11 is a block diagram illustrating a fifth embodiment of the invention.

[0031] FIG. 12 shows shading images of examples of filters prepared in a first filter file 811 of FIG. 11.

[0032] FIG. 13 shows shading images of examples of filters prepared in a second filter file 812 of FIG. 11.

[0033] FIG. 14 is a diagram illustrating principle of a prior art.

[0034] Now, embodiments of the present invention will be described in connection with the drawings.

[0035] Referring to FIG. 1, a first embodiment of the invention comprises a image memory 11 for storing image data of such skin patterns as fingerprint pattern images, a filter file 15 for storing filters prepared for filtering the image data read out from the image memory 11, filtering means 12 for filtering the image data by convolution calculation each by each with filters stored in the filter file 15, image intensity calculation means 13 for calculating image intensities of subregions of each of the filtered data, and feature extracting means 14 for determining features of predetermined subregions of the image data, in accordance with the results calculated in the image intensity calculation means 13.

[0036] The image memory 11 is composed of a hard disk memory or a DRAM for storing digital image data of skin pattern images as fingerprint pattern images or palm print pattern images collected by an input device as a CCD camera or an image scanner.

[0037] In the filter file 15, a plurality of filters used by the filtering means 12 are prepared according to a kind of features to be extracted in a DRAM for example.

[0038] In the following descriptions, a set of image data stored in the image memory 11 is assumed to be data of 512×512 pixels with resolution of 20 pixels per mm, and is expressed by a function $g(x,y)$ representing pixel values at coordinates (x,y), where $x = 0, 1, 2, 511$ and $y = 0, 1, 2, \ldots, 511$.

[0039] Now, the convolution calculation, and its correspondence to Fourier transform performed in the filtering means 12 is described, taking the case for extracting features of ridge line pitches as an example.

[0040] When image data are expressed by $g(x, y)$ ($x = 0, 1, \ldots, m - 1$ and $y = 0, 1, \ldots, n-1$) and a filter is expressed by $h(x,y)$ ($x = 0, 1, \ldots, m_h-1$ and $y = 0, 1, 2, \ldots, n_h - 1$), the convolution $z(x, y)$ of the image data $g(x,y)$ and a filter $h(x,y)$ is calculated as following equation (1).

$$z(x,y) = \sum_{i=0}^{m_h-1} \sum_{j=0}^{n_h-1} g(x-i, y-j) \cdot h(i,j) \tag{1}$$

[0041] This convolution calculation on a real plane is equivalent with a product calculation represented by following equation (2) of each frequency component on a Fourier transformed plane.

$$\begin{aligned} F\{g(x, y) * h(x, y)\} &= F\{g(x, y)\} \cdot F\{h(x, y)\} \\ &= G(u, v) \cdot H(u, v) \end{aligned} \tag{2}$$

where, $A * B$ means convolution of A and B, $F\{A\}$ means two-dimensional Fourier transform of A, and $G(u,v)$ and $H(u, v)$ mean the Fourier transforms of $g(x,y)$ and $h(x,y)$ expressed on the Fourier transformed plane respectively.

[0042] The two-dimensional Fourier transform is calculated as following equation (3).

$$F\{g(x,y)\} = G(u,v) = \frac{1}{\sqrt{mn}} \sum_{x=0}^{m-1} \sum_{y=0}^{n-1} g(x,y) \exp\left(-j2\pi\left(\frac{xu}{m} + \frac{yv}{n}\right)\right) \quad (3)$$

where $u = 0, 1, ..., m - 1$ and $v = 0, 1, ..., n - 1$.

[0043] And by following equation (4), inverse Fourier transform, a Fourier transform is transferred on the real plane.

$$g(x,y) = F^{-1}\{G(u,v)\} = \frac{1}{\sqrt{mn}} \sum_{u=0}^{m-1} \sum_{v=0}^{n-1} G(u,v) \exp\left(j2\pi\left(\frac{xu}{m} + \frac{yv}{n}\right)\right) (4)$$

[0044] Here, for shifting the direct current component $G(0,0)$ to a center of the Fourier transformed plane, Fourier transform of $(-1)^{x+y}g(x,y)$, hereafter called an optical Fourier transform, is often used for convenience of calculation.

[0045] Returning to FIG. 1, preparation of filters for extracting features of ridge line pitches in the filter file 15 will be described.

[0046] For preparing a filter which filters out images of pitch frequency under R_1 and over R_2, an ideal band-pass filter $H(u,v)$ represented by following equation (5) and illustrated in FIG. 2 is designed on an optical Fourier transformed plane.

$$H(u,v) = \begin{cases} a & \text{when } R_1 \le (u^2 + v^2)^{1/2} \le R_2 \\ 0 & \text{otherwise.} \end{cases} \quad (5)$$

[0047] Here, a is a constant for normalizing outputs of different filters, determined as follows, for example.

$$a = 1/(R_2^2 - R_1^2) \quad (6)$$

[0048] When the resolution of an image is 20 pixels per mm, the ridge line pitches are in a range from about 5 pixels to 20 pixels. This range from about 5 pixels to 20 pixels corresponds to a frequency range from about 100 cycles to 25 cycles, difining 512 pixels as a cycle.

[0049] This frequency range from 25 cycles to 100 cycles (a frequency band of 75 cycles) is divided into five ranges of frequency band of 15 cycles each, for example, for designing five filters corresponding to each thereof as shown by h_1 to h_5 in FIG. 3.

[0050] Then, from these filters $H_i(u, v)$ (i = 1, 2, ..., 5) designed on the optical Fourier transformed plane, inverse Fourier transforms are calculated for obtaining filters $h_i(x, y)$ (i = 1, 2, ...,1 5) to be applied for convolution calculation on the real plane. In this inverse Fourier transform, higher frequency components are ignored for simplifying the convolution calculation. Thus, filters on the real plane are obtained approximating corresponding ideal band-pass filters h_1 to h_5 of FIG. 3. In the example, filter size of these transformed filters is 64 × 64 pixels. FIG. 4 shows shading images of these five filters defined by h_1 to h_5 of FIG. 3. The data of these filters shown in FIG. 4 are stored in the filter file 15.

[0051] In the filtering means 12, a convolution calculation expressed by the equation (1) is performed. When each of the five filters is denoted by $h_i(x, y)$ (i = 1, 2, ..., 5), filtered data obtained through filtering by a filter $h_i(x,y)$ are expressed by $g_i(x,y)$ as follows,

$$g_{i=}(x, y) = g(x, y) * h_i(x, y) \quad (7)$$

Five sets of filtered data $g_i(x, y)$ (i = 1, 2, ..., 5) are delivered to the image intensity calculation means 13.

[0052] In the image intensity calculation means 13, image intensities $P(i,m,n)$ of predetermined subregions $C(m, n)$ of each set of the filtered data $g_i(x,y)$ are calculated as following equation (8),

$$P(i,m,n) = \sum_{(x,y)\in C(m,n)} g_i(x,y)^2 \qquad (8)$$

[0053] Here, in the embodiment, each of the subregions $C(m, n)$ is defined as a square region consisting of 32 × 32 pixels as shown in FIG. 5, having its center on coordinates (m, n) arranged by every 16 pixels in x and y direction of the plane of 512 × 512 pixels, as represented by a bullet in FIG. 5, of each set of filtered data.

[0054] The image intensity calculation means 13 delivers the calculated results $P(i, m, n)$ to the feature extracting means 14. The feature extracting means 14 determine features of the predetermined subregions of the skin pattern image. When a filter $h_1(x,y)$, for example, represented by h_1 in FIG. 3 gives the maximum value of the image intensities $P(i,m,n)$ (i = 1, 2, ..., 5) for a subregion $C(m, n)$, ridge line pitch Qfeature τ of the subregion $C(m, n)$ is calculated as follows.

$$\tau = \frac{512}{(R_1 + R_2)/2}$$

$$= \frac{512}{(25 + 40)/2} = 15.7\text{pixels} \qquad (9)$$

[0055] Thus, features for every subregion are determined in the feature extracting means 14.

[0056] Now, a second embodiment of the invention is described, wherein filtering of skin pattern images are performed by product calculation of each frequency component of the Fourier transforms.

[0057] FIG. 6 is a block diagram of another filtering means 24 of the second embodiment corresponding to the filtering means 12 of FIG. 1, comprising Fourier transformation means 21 for performing two-dimensional optical Fourier transform of image data read out from the image memory 11, masking means 22 for performing product calculation between image data deliverd from the Fourier transformation means 21 and filters prepared in a filter file 25, and inverse Fourier transformation means 23 for performing inverse optical Fourier transform of the masked data obtained from the masking means 22.

[0058] The embodiment is described following the example applied in connection with the first embodiment for extracting features of ridge line pitches of a skin pattern image.

[0059] In the filter file 25, the ideal band-pass filters $H_i(u, v)$ (i = 1, 2, ...5) designed on the optical Fourier transformed plane having data of 512 × 512 pixels are stored intact without transformation. The Fourier transformation means 21 transforms the skin pattern image $g(x,y)$ according to the equation (3) for obtaining an optical Fourier transform $G(u, v)$ thereof.

[0060] In the masking means 22, real and imaginary part of each frequency component of the Fourier transform $G(u, v)$ are multiplied by those of the five band-pass filters $Hi(u, v)$ one by one.

[0061] Five sets of masked data $G_i(u, v) = G(u, v) \bullet H_i(u, v)$ are processed with inverse optical Fourier transform described in connection with the equation (4) in the inverse Fourier transformation means 23 for obtaining five sets of filtered data $g_i(x, y)$ to be processed in the image intensity calculation means 13 of FIG. 1 as same as in the first embodiment.

[0062] Filtering by convolution calculation as performed in the first embodiment needs a number of operations proportional to the filter size. So, the filters for convolution calculation are generally restrained in a size, 64 × 64 in the example described, accompanied with inevitable approximation.

[0063] On the other hand, for filering by masking calculation as performed in the second embodiment, ideal band-pass filters can be desigend in a finite Fourier transformed plane with no approximation. Further more, for image data with its sides expressed by a power of 2, fast Fourier transform can be applied for high speed calculation.

[0064] It is apparent that the optical Fourier transform can be replaced with the fast Fourier transform or an ordinary digital Fourier transform by preparing appropriate filters. Therefore, it can be said that there are more merits in the second embodiment compared to the first embodiment when filter size is not sufficiently small.

[0065] Now, a third embodiment will be described, wherein the feature extracting means 14 of FIG. 1 is replaced with another feature extracting means 30 illustrated in FIG. 7.

[0066] In the third embodiment, there is defined an evaluation function, variable of which are feature parameters of each subregion, representing sum total of image intensities (multiplied by -1) of all subregion and sum total of square sums of differences between values of the feature parameter of each subregion and that of neighbouring subregions. Each of the feature parameters which gives the minimum value of the evaluation function is determined as the feature of each subregion in the third embodiment.

[0067] For the purpose, the feature extracting means 30 of FIG. 7 comprises minimizing means 31 and initial value

calculation means 32.

[0068] From the image intensity calculation means 13 of FIG. 1, the image intensities $P(i, m, n)$ are delivered to the initial value calculation means 31 for determining initial values $s_0(m,n)$ of feature parameters, namely ridge line pitches that give a highest value of the image intensities $P(i,m,n)$ of each subregion $C(m,n)$ as same as in the first embodiment.

[0069] The map of the initial values $s_0(m,n)$ for all the subregions shows an initial two-dimensional feature pattern of the skin pattern image. For smoothing the initial two-dimensional feature pattern, the initial value $s_0(m,n)$ of a concerning subregion $C(m,n)$ is replaced with a most appropriate value $s(m,n)$, among five values of feature parameters, which gives a minimum value of the evaluation function $E(s(m,n))$ represented by a following equation (10) in the minimizing means 31.

$$E(s(m,n)) = -\sum_{(m,n)} P(s(m,n),m,n) + \sum_{(m,n)} \sum_{(m',n')} D(s(m,n), s_0(m',n')) \qquad (10)$$

where, (m',n') means coordinates of neighbouring subregions of the concerning subregion $C(m, n)$, $5 \times 5 - 1$ subregions shown in FIG. 8 in an example, and $D(s(m, n), s_0(m', n'))$ is a function representing singularity of a value $s(m, n)$, namely the current feature parameter, among its neighbourhood, expressed as follows in an example, α being a coefficient.

$$D(s(m, n), s_0(m', n')) = \alpha\{s(m, n) - s_0(m', n')\}^2 \qquad (11)$$

[0070] Thus, the minimization of the evaluation function $E(s(m,n))$ is performed for every subregion $C(m, n)$ replacing initial value $s_0(m, n)$ by an appropriate value $s(m,n)$ one by one, and these processes are repeated several times determined for converging the minimization as shown by a flowchart illustrated in FIG. 9.

[0071] In step 41, initial value of the evaluation function E is calculated according to the equation (10) with the initial values $s_0(m,n)$ of feature parameters. Then, in step 42, value of the evaluation function E is recalculated for a subregion $C(m, n)$ with other values $s_{i\neq 0}(m, n)$ one by one (checked in step 45) for replacing the initial value $s_0(m, n)$ (in step 44) when the evaluation function E is found reduced (in step 43). Steps 42 to 46 are performed for all subregions $C(m, n)$ through step 46 and repeated several times through step 47.

[0072] Thus a smoothed two-dimensional feature pattern giving the minimum value of the evaluation function E is obtained in the embodiment.

[0073] Now referring to FIG. 10, a fourth embodiment providing a skin pattern image processor is described, wherein the extracting method of skin pattern features of the invention is applied.

[0074] In the block diagram of FIG. 10, pixel value calculation means 75 are comprised in addition to the block diagram referred to in connection with the first, second or the third embodiment, for generating image data of a feature enhanced skin pattern.

[0075] Taking the example of FIG. 5, each pixel belongs to four subregions since the subregions are defined overlapped. Therefore, at most four values are obtained for each pixel from filtered data sets corresponding to features assigned to the four subregions where the pixel belongs. Average of these at most four values for each pixel is output as each pixel value of the image data of the feature enhanced skin pattern image.

[0076] In a fifth embodiment illustrated in FIG. 11, skin pattern image processors of FIG. 10 are cascaded for enhancing plural kinds of features of skin pattern image data. An example of the embodiment of FIG. 11 consists of two skin pattern image processors 80 and 81, wherein skin pattern image data enhanced of ridge line pitch features by the skin pattern processor 80 are stored in a second image memory 806 to be processed with filters prepared for extracting ridge line direction features of the skin pattern image data.

[0077] Therefore, a more smoothed skin pattern image can be obtained with features of two kinds enhanced in the embodiment.

[0078] It goes without saying that feature data of each kind, to be used for classifying skin pattern images for example, can be obtained also in the embodiment from each feature extracting means 804 and 809 in addition to the feature enhanced skin pattern.

[0079] The embodiments are described heretofore in connection with the example provided of five filters for extracting ridge line pitch features. However, any other appropriate filters can be used for extracting desired features of skin pattern images and processing them for enhancing the desired features thereof.

[0080] In the following paragraphs, other examples of filter sets prepared for masking Fourier transforms of skin pattern image data are described.

[0081] FIG. 12 shows shading images of a filter set consisting of ten band-pass filters for extracting ridge line pitch features by masking optical Fourier transforms of skin pattern image data prepared in a first filter file of 811 of the embodiment of FIG. 11. Pixel values $W_r(|r|)$ of each of the band-pass filters of FIG. 12 are represented by following equation (12) symmetric with respect to its origin.

$$W_r(|\boldsymbol{r}|) = \frac{1}{|\boldsymbol{r}|}\exp\left(-\frac{(|\boldsymbol{r}|-r_0)^2}{2\sigma_r^2}\right) / \int \frac{1}{|\boldsymbol{r}|}\exp\left(-\frac{(|\boldsymbol{r}|-r_0)^2}{2\sigma_r^2}\right) d|\boldsymbol{r}| \quad (12)$$

where vector r denotes coordinates of a pixel on an optical Fourier transformed plane of 512 × 512 pixels with origin at its center, r_0 and σ_r corresponding to a center frequency and a frequency width of pass-band respectively of each of the ten band-pass filters.

[0082] In the examples of FIG. 12, r_0 are arranged by every 5.7 pixels from 28.4 to 79.6 pixels on condition σ_r is 12.0.

[0083] By the way, shading images in FIG. 12 show center regions of the band-pass filters and the brighter dot represents the larger pixel value, darkest dot representing pixel value of 0.

[0084] FIG. 13 shows shading images of another filter set consisting of 16 directional filters for extracting ridge line direction features by masking Fourier transforms of skin pattern image data prepared in a second filter file 812 of the example of FIG. 11. Pixel values $W_\theta(r)$ of each of the directional filters of FIG. 13 are represented by following equation (13) line symmetric.

$$W_\theta(\boldsymbol{r}) = \exp\left(-\frac{1}{2\sigma_\theta^2}\left(\cos^{-1}\frac{|\boldsymbol{r}\cdot \boldsymbol{e}_\theta|}{|\boldsymbol{r}|}\right)^2\right) \quad (13)$$

where, e_θ = (cosθ; sinθ) denotes unit vector of each direction θ represented by each of the directional filters and σ_θ, 0.4 in the examples of FIG. 13, is a parameter representing phase angle width of the pass-band.

[0085] As for the singulality function $D(s(m,n), s_0(m',n'))$ in the evaluation function E of the equation (10), Euclidean distances expressed by following equation (14) are better to be applied here, for smoothing directional features by directional filtering, instead of the equation (11).

$$D(s(m, n), s_0(m', n')) = \alpha\{(\sin 2\theta(m, n) - \sin 2\theta(m', n'))^2 + (\cos 2\theta(m, n) - \cos 2\theta(m', n'))^2\} \quad (14)$$

where $\theta(m, n)$ is directional feature of a subregion $C(m, n)$.

[0086] Thus, by smoothing ridge direction features of a skin pattern image after smooting its ridge line pitch features, or vice versa, a more enhancing and reliable image processing can be provided in the present invention.

[0087] Returning to FIG. 11, two skin pattern image processors of FIG. 10 are cascaded in the fifth embodiment for obtaining smoothed skin pattern images with their features of two kinds enhanced or extracting two kinds of features. However, by preparing filters according to kinds of features to be extracted or enhanced, plural kinds of features can be extracted or enhanced of a skin pattern image with one skin pattern image processor.

[0088] In a sixth embodiment having the same configuration with the fourth embodiment of FIG. 10, a filter set for extracting and enhancing plural kinds of features, ridge line pitch features and ridge line direction features for example, is prepared in the filter file 25.

[0089] For preparing the filter set corresponding to the filter sets of FIG. 12 and FIG. 13, each filter is given from a product $W_{\theta,r}(r)$ of a filter of FIG. 12 expressed by the equation (12) and a filter of FIG. 13 expressed by the equation (13) as follows.

$$W_{\theta,r}(r) = W_\theta(r)W_r(|r|) = \exp\left(-\frac{1}{2\sigma_\theta^2}(\cos^{-1}\frac{|r \cdot e_\theta|}{|r|})^2\right) \cdot \frac{\frac{1}{|r|}\exp(-\frac{(|r|-r_0)^2}{2\sigma_r^2})}{\int \frac{1}{|r|}\exp(-\frac{(|r|-r_0)^2}{2\sigma_r^2})d|r|} \quad (15)$$

[0090] If the ridge line pitch features are to be classified into ten values of r_0 and the ridge line direction feachures are to be classifyed into 16 values of θ as same as FIGs. 12 and 13, a set of 160 filters is thus prepared.

[0091] In the image intensity calculation means 13 of the sixth embodiment, image intensities $P(\theta, r_0, m, n)$ of the predetermined subregions $C(m, n)$ are calculated for every 160 filtered data $g(\theta, r_0, x, y)$ obtained from the skin pattern image $g(x,y)$ by filtering with the 160 filters $W_{\theta,r}(r)$ as follows in a same way as the equation (8).

$$P(\theta, r_0, m, n) = \sum_{(x,y)\in C(m,n)} g(\theta, r_0, x, y)^2$$

[0092] In the feature extracting means 30 of the sixth embodiment, vector values

$$v(m,n) = \binom{\theta(m,n)}{r_0(m,n)}$$

representing ridge line pitch featuers and ridge line direction features for the predetermined subregions $C(m, n)$ are obtained from the image intensities $P(\theta, r_0, m, n)$ calculated by the image intencity calculation means 13 in a similar way as described in connection with FIGs. 7 to 9.

[0093] In the initial value calculation means 32, initial values $v_0(m,n)$ are calculated from parameters (θ, r_0) of filters $W_{\theta,r}(r)$ which give maximum intencities $P(\theta, r_0, m,n)$ of filtered data for the predetermined subregions $C(m, n)$. Starting from the initial values $v_0(m,n)$, a two-dimensional feature pattern of the vector values $v(m,n)$ is determined in the minimizing means 31 to minimize an evaluation function represented by a following equation (16).

$$E(v(m,n)) = -\sum_{(m,n)} P(\theta, r_0, m, n) + \sum_{(m,n)} \sum_{(m',n')} D(v(m,n), v_0(m',n')) \quad (16)$$

where,

$$D(v(m,n), v_0(m',n')) = \alpha\{(\sin 2\theta(m,n) - \sin 2\theta(m',n'))^2 + (\cos 2\theta(m,n) - \cos 2\theta(m',n'))^2\} + \beta\{r_0(m,n) - r_0(m',n')\}^2$$

[0094] Thus, two kinds of features of each subregion of a skin pattern image are extracted in the sixth embodiment. The smoothed skin pattern image is obtained by the pixel value calculation means 75 in the same way with the fourth embodiment from filtered data corresponding to the two kinds of features extracted for each subregion.

[0095] And as beforehand described; still more kinds of features can be extracted and still more kinds of filtering or smoothing can be performed with still more kinds of filter sets in the scope of the invention.

Claims

1. An apparatus for extracting features of predetermined subregions of a skin pattern image, comprising:

   an image memory (11) for storing image data of the skin pattern image;
   a filter file (15) for storing a plurality of filters consisting of two-dimensional data prepared according to the features to be extracted;
   filtering means (12) for outputting filtered data sets, each of said filtered data sets obtained from said image data by convolution calculation with each of said plurality of filters;
   image intensity calculation means (13) for calculating image intensity of each of the predetermined subregions of each of said filtered data sets; and
   feature extracting means (14) for determining the features of the predetermined subregions of the skin pattern image referring to said image intensity of each of the predetermined subregions of each of said filtered data sets, wherein
   said feature extracting means (14) determine the features of the predetermined subregions of the skin pattern image according to feature parameters minimizing an evaluation function, said evaluation function being a linear function of said image intensity of each of the subregions of one of said filtered data sets corresponding to a feature parameter assigned to said each of the subregions, and a value corresponding to singularity of said feature parameter assigned to said each of the predetermined subregions compared to the feature parameters assigned to certain of the predetermined subregions neighbouring to said each of the predetermined subregions.

2. An apparatus for extracting features of predetermined subregions of a skin pattern image, comprising:

   an image memory (11) for storing image data of the skin pattern image;
   a filter file (15) for storing a plurality of filters consisting of two-dimensional data prepared according to the features to be extracted;
   filtering means (24) for outputting filtered data sets, each of said filtered data sets being an inverse Fourier transform of a masked data set obtained from a Fourier transform of said image data by product calculation of each frequency component of said Fourier transform and each of said plurality of filters;
   image intensity calculation means (13) for calculating image intensity of each of the predetermined subregions of each of said filtered data sets; and
   feature extracting means (14) for determining the features of the predetermined subregions of the skin pattern image referring to said image intensity of each of the predetermined subregions of each of said filtered data sets, wherein
   said feature extracting means (14) determine the features of the predetermined subregions of the skin pattern image according to feature parameters minimizing an evaluation function, said evaluation function being a linear function of said image intensity of each of the subregions of one of said filtered data sets corresponding to a feature parameter assigned to said each of the subregions, and a value corresponding to singularity of said feature parameter assigned to said each of the predetermined subregions compared to the feature parameters assigned to certain of the predetermined subregions neighbouring to said each of the predetermined subregions.

3. An apparatus according to claim 1 or 2, further comprising pixel value calculating means for calculating a value of each pixel of the filtered skin pattern image from values of pixels of those of said filtered data sets that correspond to each of the features extracted of the predetermined subregions where said each pixel belongs.

Patentansprüche

1. Vorrichtung zum Extrahieren von Merkmalen vorgegebener Unterbereiche eines Hautmusterbildes, mit:

   einem Bildspeicher (11) zum Speichern von Bilddaten des Hautmusterbildes;
   einer Filterdatei (15) zum Speichern mehrerer Filter, die aus zweidimensionalen Daten bestehen, die in Übereinstimmung mit den zu extrahierenden Merkmalen vorbereitet worden sind;
   Filterungseinrichtungen (12) zum Ausgeben gefilterter Datenmengen, wobei jede der gefilterten Datenmengen aus den Bilddaten durch eine Faltungsberechnung mit jedem der mehreren Filter erhalten wird;
   einer Bildintensität-Berechnungseinrichtung (13) zum Berechnen der Bildintensität jedes der vorgegebenen

Unterbereiche jeder der gefilterten Datenmengen; und
einer Merkmalsextraktionseinrichtung (14) zum Bestimmen der Merkmale der vorgegebenen Unterbereiche des Hautmusterbildes, die auf die Bildintensität jedes der vorgegebenen Unterbereiche jeder der gefilterten Datenmengen Bezug nimmt, wobei
die Merkmalsextraktionseinrichtung (14) die Merkmale der vorgegebenen Unterbereiche des Hautmusterbildes in Übereinstimmung mit Merkmalsparametern bestimmt, die eine Bewertungsfunktion, die eine lineare Funktion der Bildintensität jedes der Unterbereiche einer der gefilterten Datenmengen, die einem jedem der Unterbereiche zugewiesenen Merkmalsparameter entspricht, sowie eines Wertes, der einer Singularität des jedem der vorgegebenen Unterbereiche zugewiesenen Merkmalsparameters entspricht, ist, im Vergleich zu den Merkmalsparametern, die bestimmten der vorgegebenen Unterbereiche zugewiesen sind, die dem vorgegebenen Unterbereich benachbart sind, minimieren.

2. Vorrichtung zum Extrahieren von Merkmalen vorgegebener Unterbereiche eines Hautmusterbildes, mit:

einem Bildspeicher (11) zum Speichern von Bilddaten des Hautmusterbildes;
einer Filterdatei (15) zum Speichern mehrerer Filter, die aus zweidimensionalen Daten bestehen, die in Übereinstimmung mit den zu extrahierenden Merkmalen vorbereitet wurden;
einer Filterungseinrichtung (24) zum Ausgeben gefilterter Datenmengen, wobei jede der gefilterten Datenmengen eine inverse Fourier-Transformation einer maskierten Datenmenge ist, die aus einer Fourier-Transformation der Bilddaten durch Produktberechnung jeder Frequenzkomponente der Fourier-Transformation und jedes der mehreren Filter erhalten wird;
einer Bildintensität-Berechnungseinrichtung (13) zum Berechnen der Bildintensität jedes der vorgegebenen Unterbereiche jeder der gefilterten Datenmengen; und
einer Merkmalsextraktionseinrichtung (14) zum Bestimmen der Merkmale der vorgegebenen Unterbereiche des Hautmusterbildes, die auf die Bildintensität jedes der vorgegebenen Unterbereiche jeder der gefilterten Datenmengen Bezug nimmt; wobei
die Merkmalsextraktionseinrichtung (14) die Merkmale der vorgegebenen Unterbereiche des Hautmusterbildes in Übereinstimmung mit Merkmalsparametern bestimmt, die eine Bewertungsfunktion, die eine lineare Funktion der Bildintensität jedes der Unterbereiche einer der gefilterten Datenmengen, die einem jedem der Unterbereiche zugewiesenen Merkmalsparameter entspricht, sowie eines Wertes, der einer Singularität des jedem der vorgegebenen Unterbereiche zugewiesenen Merkmalsparameters entspricht, ist, im Vergleich zu den Merkmalsparametern, die bestimmten der vorgegebenen Unterbereiche zugewiesen sind, die dem vorgegebenen Unterbereich benachbart sind, minimieren.

3. Vorrichtung nach Anspruch 1 oder 2, ferner mit einer Pixelwert-Berechnungseinrichtung zum Berechnen eines Wertes jedes Pixels des gefilterten Hautmusterbildes aus Werten von Pixeln jener Datenmenge der jedem der Merkmale entsprechenden gefilterten Datenmengen, die aus den vorgegebenen Unterbereichen, zu denen jedes Pixel gehört, extrahiert worden ist.

Revendications

1. Dispositif pour extraire des caractéristiques de sous-régions prédéterminées d'une image de motif de peau, comportant :

une mémoire d'image (11) pour mémoriser des données d'image de l'image de motif de peau,
un fichier de filtres (15) pour mémoriser une pluralité de filtres constitués de données bidimensionnelles préparées en fonction des caractéristiques à extraire,
des moyens de filtrage (12) pour délivrer en sortie des ensembles de données filtrées, chacun desdits ensembles de données filtrées étant obtenu à partir desdites données d'image par un calcul de convolution à l'aide de chaque filtre de ladite pluralité de filtres,
des moyens de calcul d'intensité d'image (13) pour calculer l'intensité d'image de chacune des sous-régions prédéterminées de chacun desdits ensembles de données filtrées,
des moyens d'extraction de caractéristiques (14) pour déterminer les caractéristiques des sous-régions prédéterminées de l'image de motif de peau se rapportant à ladite intensité d'image de chacune des sous-régions prédéterminées de chaque ensemble desdits ensembles de données filtrées, **caractérisé en ce que**
lesdits moyens d'extraction de caractéristiques (14) déterminent les caractéristiques des sous-régions prédéterminées de l'image de motif de peau en fonction de paramètres de caractéristiques minimisant une fonction

d'évaluation, ladite fonction d'évaluation étant une fonction linéaire de ladite intensité d'image de chacune des sous-régions d'un ensemble parmi lesdits ensembles de données filtrées correspondant à un paramètre de caractéristique attribué à chacune desdites sous-régions, et d'une valeur correspondant à une singularité dudit paramètre de caractéristique attribué à chacune desdites sous-régions prédéterminées comparée aux paramètres de caractéristiques attribués à certaines des sous-régions prédéterminées avoisinant chacune desdites sous-régions prédéterminées.

2. Dispositif pour extraire des caractéristiques de sous-régions prédéterminées d'une image de motif de peau, comportant :

une mémoire d'image (11) pour mémoriser des données d'image de l'image de motif de peau,
un fichier de filtres (15) pour mémoriser une pluralité de filtres constitués de données bidimensionnelles préparées en fonction des caractéristiques à extraire,
des moyens de filtrage (24) pour délivrer en sortie des ensembles de données filtrées, chacun desdits ensembles de données filtrées étant une transformée de Fourier inverse d'un ensemble de données masquées obtenu à partir d'une transformée de Fourier desdites données d'image en calculant le produit de chaque composante fréquentielle de ladite transformée de Fourier et de chaque filtre de ladite pluralité de filtres,
des moyens de calcul d'intensité d'image (13) pour calculer l'intensité d'image de chacune des sous-régions prédéterminées de chaque ensemble desdits ensembles de données filtrées, et
des moyens d'extraction de caractéristiques (14) pour déterminer les caractéristiques des sous-régions prédéterminées de l'image de motif de peau se rapportant à ladite intensité d'image de chacune des sous-régions prédéterminées de chaque ensemble desdits ensembles de données filtrées, **caractérisé en ce que**
lesdits moyens d'extraction de caractéristiques (14) déterminent les caractéristiques des sous-régions prédéterminées de l'image de motif de peau en fonction de paramètres de caractéristiques minimisant une fonction d'évaluation, ladite fonction d'évaluation étant une fonction linéaire de ladite intensité d'image de chacune des sous-régions d'un ensemble parmi lesdits ensembles de données filtrées correspondant à un paramètre de caractéristique attribué à chacune desdites sous-régions, et d'une valeur correspondant à une singularité dudit paramètre de caractéristique attribué à chacune desdites sous-régions prédéterminées comparée aux paramètres de caractéristiques attribués à certaines sous-régions prédéterminées avoisinant chacune desdites sous-régions prédéterminées.

3. Dispositif selon la revendication 1 ou 2, comportant en outre des moyens de calcul de valeur de pixel pour calculer une valeur de chaque pixel de l'image de motif de peau filtrée à partir de valeurs de pixels de ces ensembles parmi lesdits ensembles de données filtrées qui correspondent à chacune des caractéristiques extraites des sous-régions prédéterminées auxquelles appartient chaque pixel.

FIG. 1

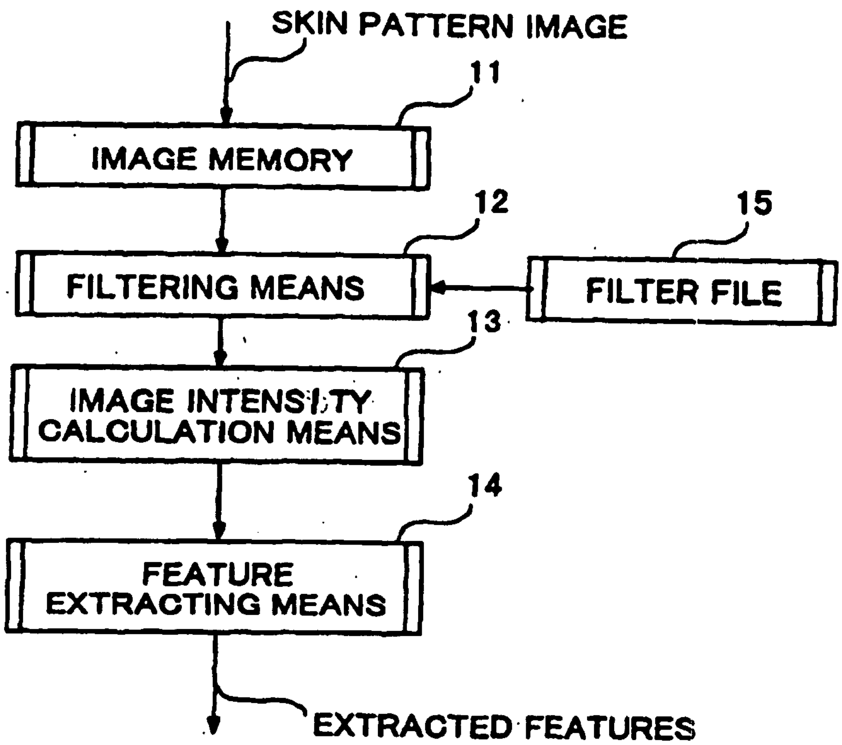

SKIN PATTERN IMAGE
11
IMAGE MEMORY
12
FILTERING MEANS
15
FILTER FILE
13
IMAGE INTENSITY CALCULATION MEANS
14
FEATURE EXTRACTING MEANS
EXTRACTED FEATURES

FIG. 2

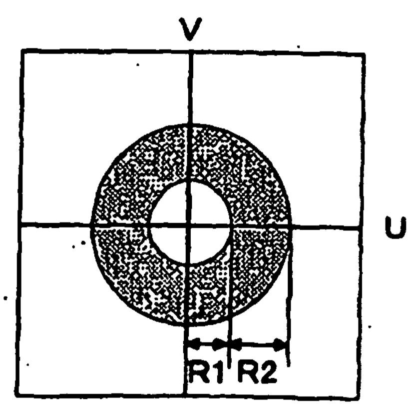
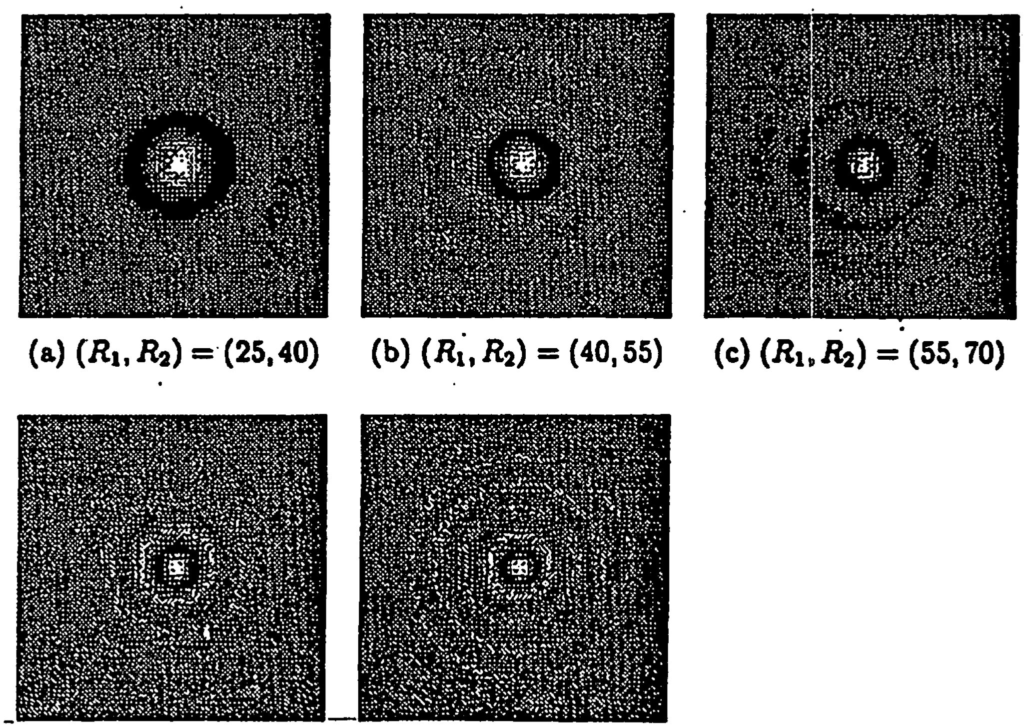

V
U
R1
R2

FIG. 3

	R_1 (cycle)	R_2 (cycle)
h_1	25	40
h_2	40	55
h_3	55	70
h_4	70	85
h_5	85	100

FIG. 4



(a) $(R_1, R_2) = (25, 40)$ (b) $(R_1, R_2) = (40, 55)$ (c) $(R_1, R_2) = (55, 70)$

(d) $(R_1, R_2) = (70, 85)$ (e) $(R_1, R_2) = (85, 100)$

FIG. 5

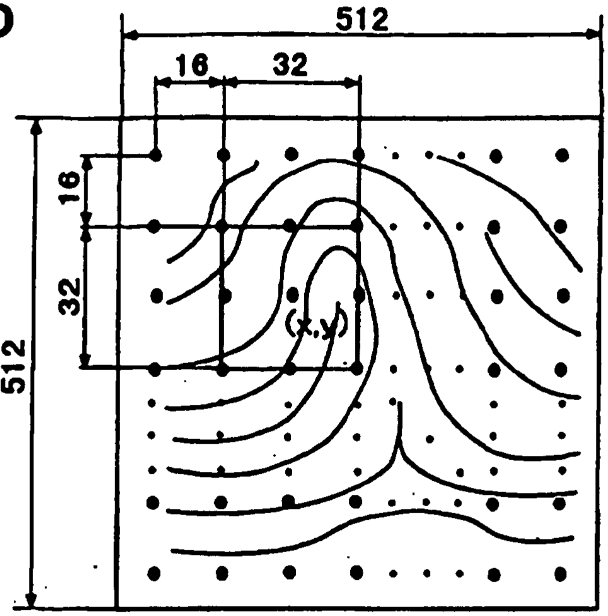

512
16
32
16
32
512
(x,y)

FIG. 6

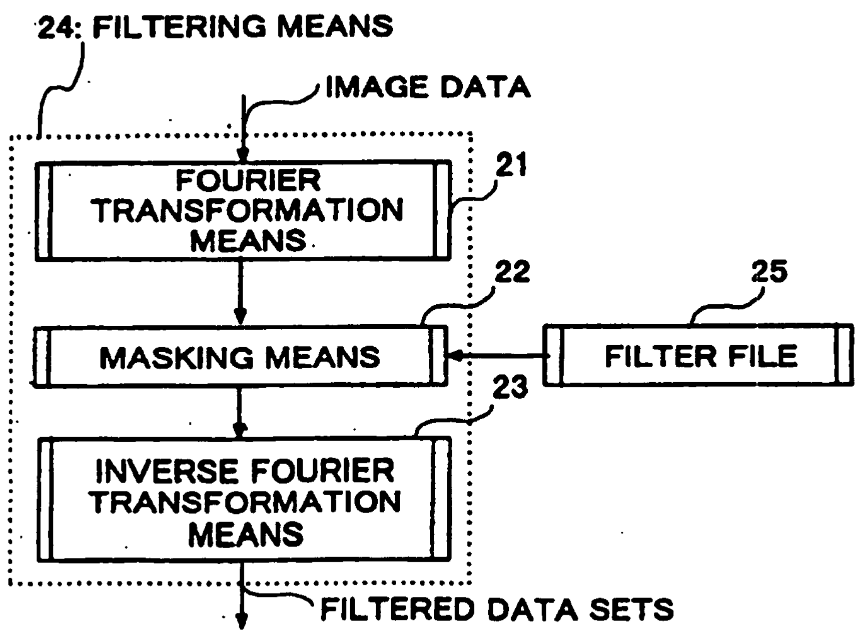

24: FILTERING MEANS
IMAGE DATA
FOURIER TRANSFORMATION MEANS
21
22
25
MASKING MEANS
FILTER FILE
23
INVERSE FOURIER TRANSFORMATION MEANS
FILTERED DATA SETS

FIG. 7

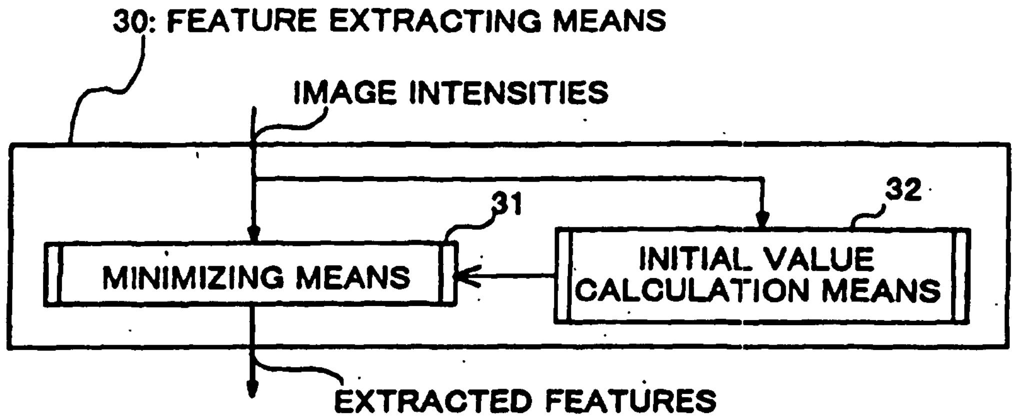
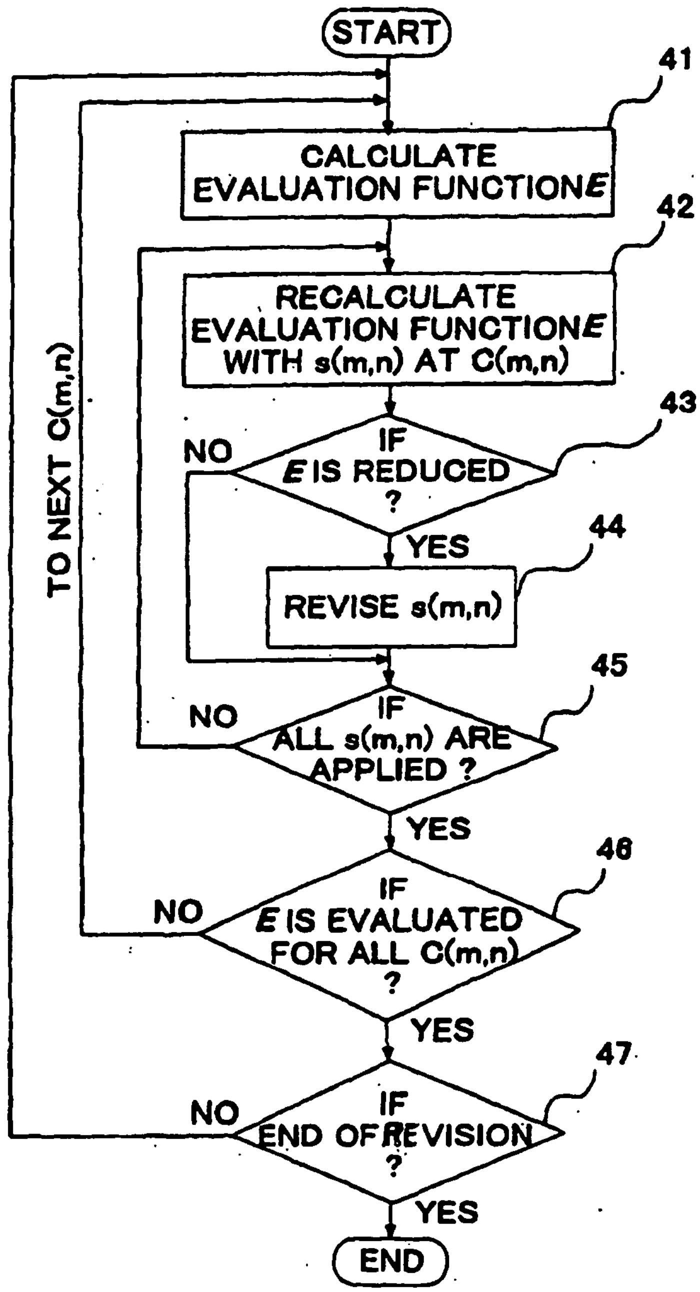


FIG. 8

(m−2,n−2)	(m−1,n−2)	(m,n−2)	(m+1,n−2)	(m+2,n−2)
(m−2,n−1)	(m−1,n−1)	(m,n−1)	(m+1,n−1)	(m+2,n−1)
(m−2,n)	(m−1,n)	(m,n)	(m+1,n)	(m+2,n)
(m−2,n+1)	(m−1,n+1)	(m,n+1)	(m+1,n+1)	(m+2,n+1)
(m−2,n+2)	(m−1,n+2)	(m,n+2)	(m+1,n+2)	(m+2,n+2)

FIG. 9



START
41
CALCULATE EVALUATION FUNCTION E
42
RECALCULATE EVALUATION FUNCTION E WITH s(m,n) AT C(m,n)
43
IF E IS REDUCED ?
NO
YES
44
REVISE s(m,n)
45
IF ALL s(m,n) ARE APPLIED ?
NO
YES
46
IF E IS EVALUATED FOR ALL C(m,n) ?
NO
YES
47
IF END OF REVISION ?
NO
YES
END
TO NEXT C(m,n)

FIG. 10

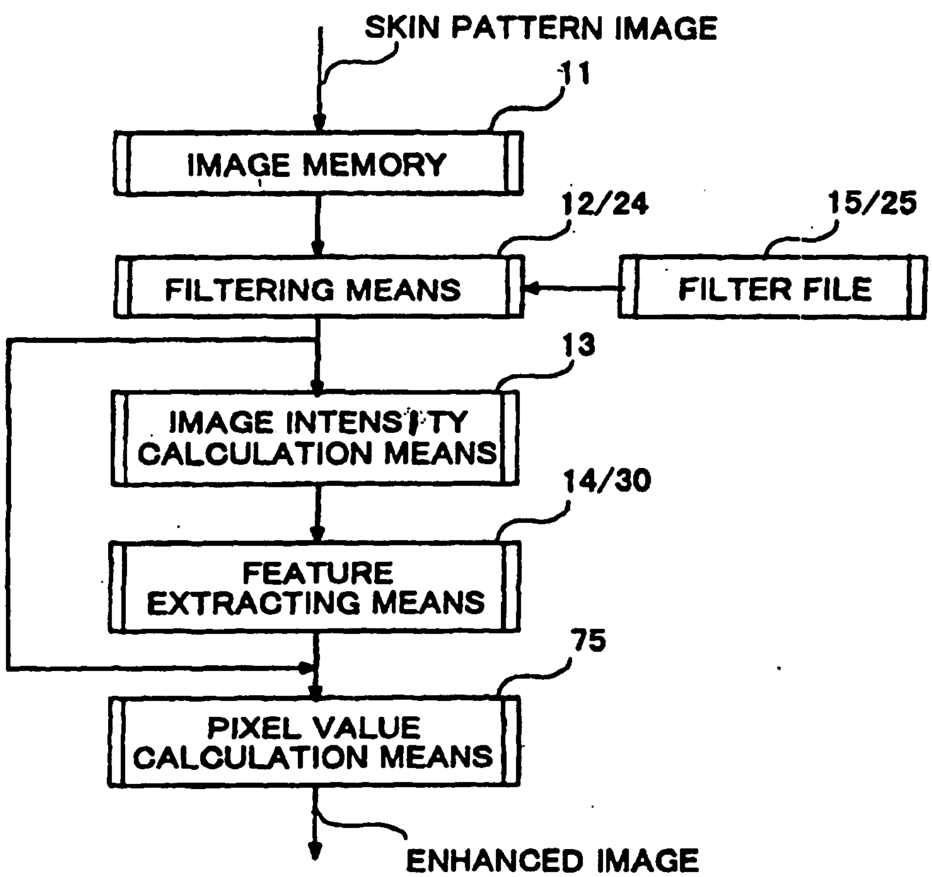

SKIN PATTERN IMAGE
11
IMAGE MEMORY
12/24
15/25
FILTERING MEANS
FILTER FILE
13
IMAGE INTENSITY CALCULATION MEANS
14/30
FEATURE EXTRACTING MEANS
75
PIXEL VALUE CALCULATION MEANS
ENHANCED IMAGE

FIG. 11

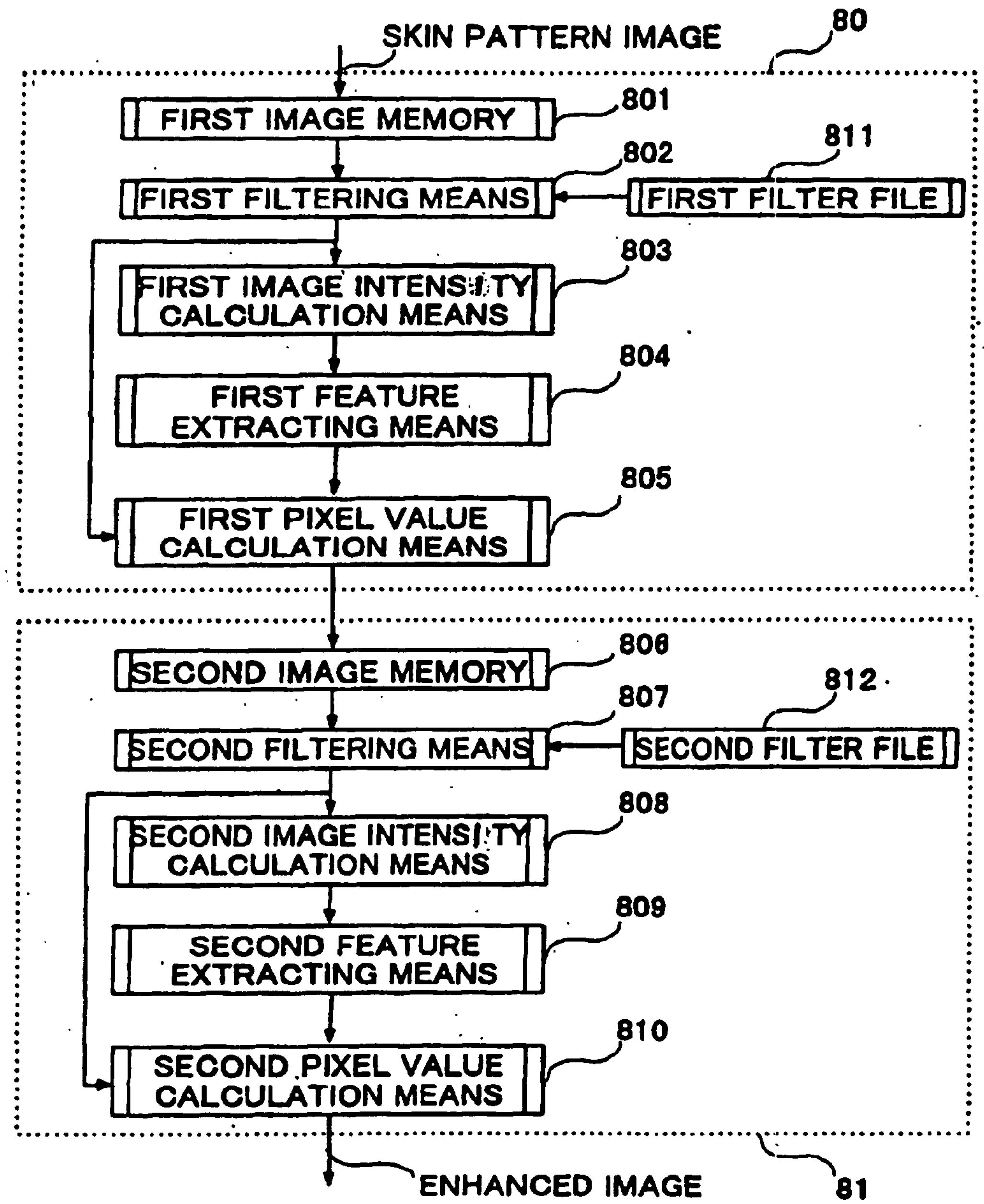

SKIN PATTERN IMAGE
80
FIRST IMAGE MEMORY
801
802
811
FIRST FILTERING MEANS
FIRST FILTER FILE
803
FIRST IMAGE INTENSITY CALCULATION MEANS
804
FIRST FEATURE EXTRACTING MEANS
805
FIRST PIXEL VALUE CALCULATION MEANS
806
SECOND IMAGE MEMORY
807
812
SECOND FILTERING MEANS
SECOND FILTER FILE
808
SECOND IMAGE INTENSITY CALCULATION MEANS
809
SECOND FEATURE EXTRACTING MEANS
810
SECOND PIXEL VALUE CALCULATION MEANS
ENHANCED IMAGE
81

FIG. 12

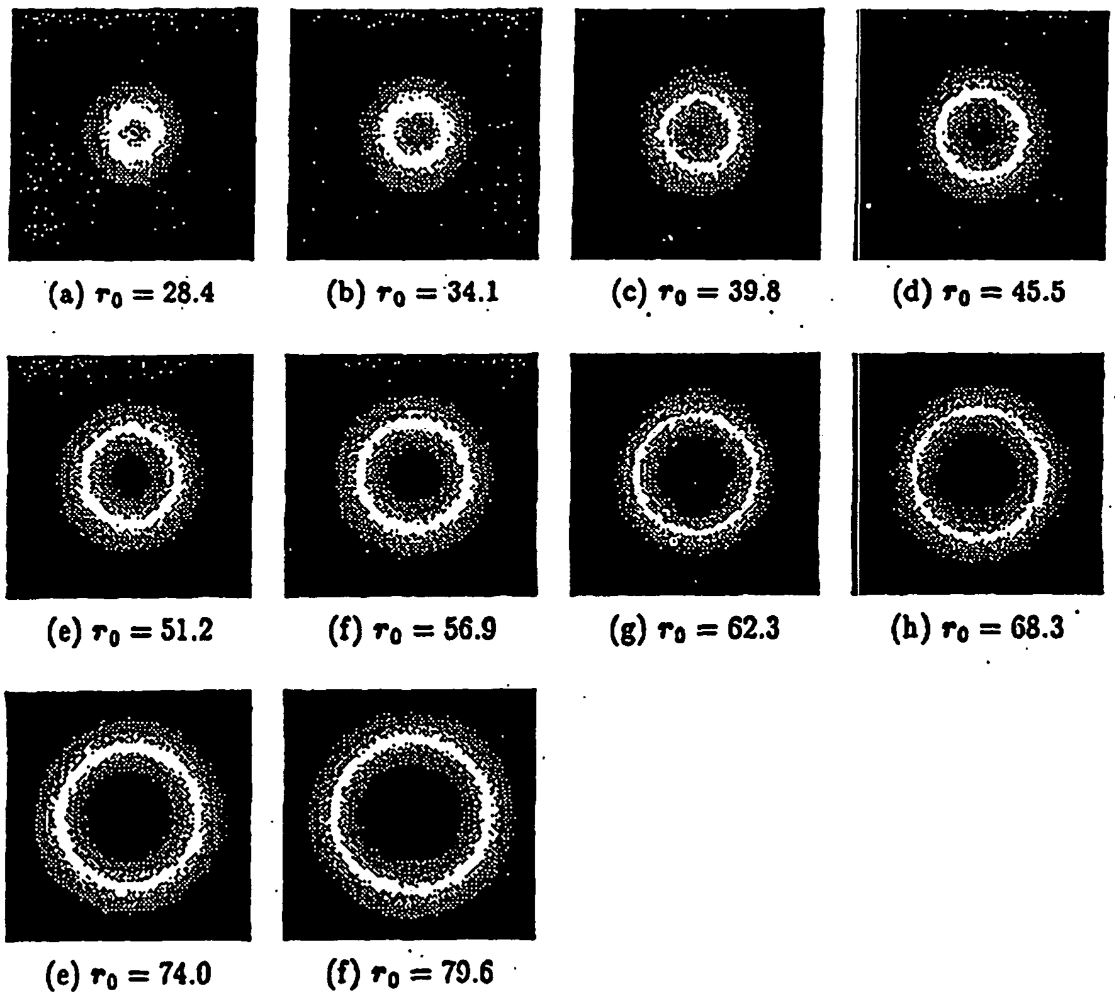
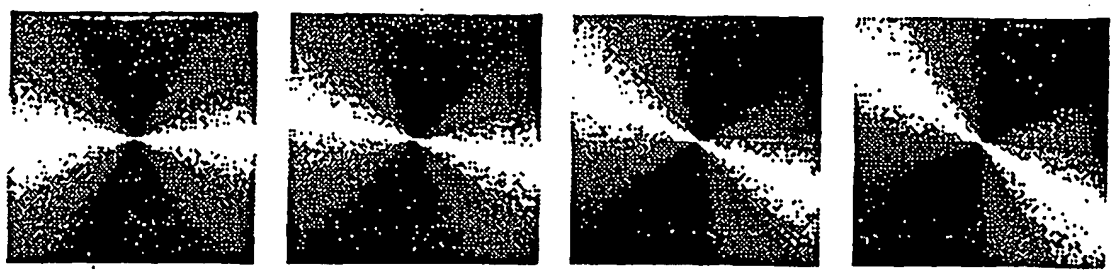
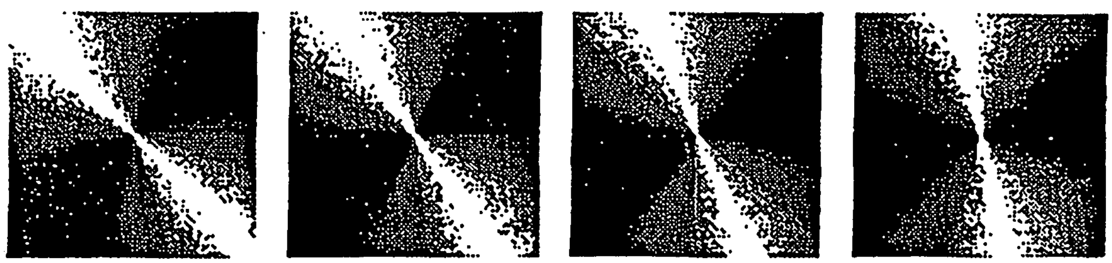

(a) $r_0 = 28.4$
(b) $r_0 = 34.1$
(c) $r_0 = 39.8$
(d) $r_0 = 45.5$
(e) $r_0 = 51.2$
(f) $r_0 = 56.9$
(g) $r_0 = 62.3$
(h) $r_0 = 68.3$
(e) $r_0 = 74.0$
(f) $r_0 = 79.6$

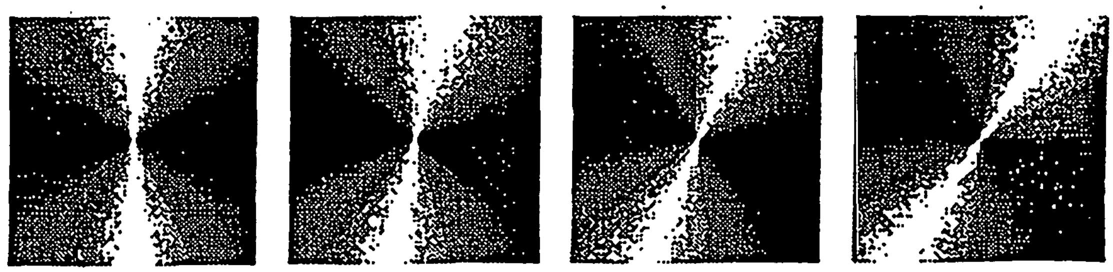
FIG. 13



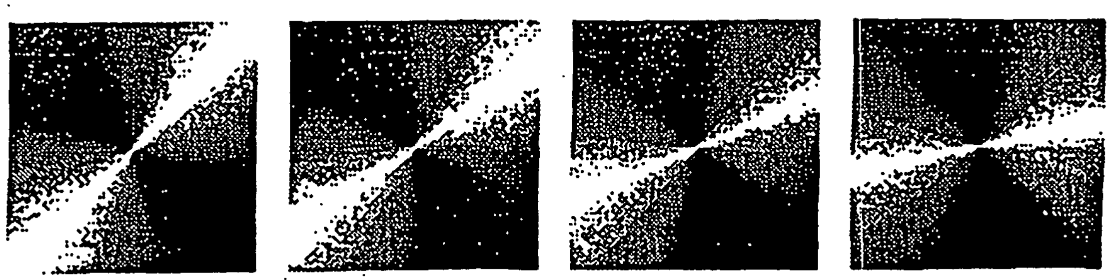
(a) $\theta = 0$ (b) $\theta = \frac{1}{16}\pi$ (c) $\theta = \frac{2}{16}\pi$ (d) $\theta = \frac{3}{16}\pi$



(e) $\theta = \frac{4}{16}\pi$ (f) $\theta = \frac{5}{16}\pi$ (g) $\theta = \frac{6}{16}\pi$ (h) $\theta = \frac{7}{16}\pi$



(i) $\theta = \frac{8}{16}\pi$ (j) $\theta = \frac{9}{16}\pi$ (k) $\theta = \frac{10}{16}\pi$ (l) $\theta = \frac{11}{16}\pi$



(m) $\theta = \frac{12}{16}\pi$ (n) $\theta = \frac{13}{16}\pi$ (o) $\theta = \frac{14}{16}\pi$ (p) $\theta = \frac{15}{16}\pi$

FIG. 14 PRIOR ART